DEPARTMENT OF COMMERCE AND LABOR
BUREAU OF STANDARDS
S. W. STRATTON, Director

A COMPARATIVE STUDY OF PLAIN AND FROSTED LAMPS

BY

EDWARD P. HYDE, Associate Physicist
and
FRANCIS E. CADY, Assistant Physicist
Bureau of Standards

[JULY 15, 1907]

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A COMPARATIVE STUDY OF PLAIN AND FROSTED LAMPS.[1]

By Edward P. Hyde and F. E. Cady.

Much attention has been given in recent years to the proper use of diffusing globes around incandescent lamps. These globes have the twofold object of hiding from view the brilliant filament and of producing a more economical distribution of the light. It has usually been considered that the same general results could be obtained by frosting the bulb of the lamp, but this method has been called into question[2] principally on account of the relatively short useful life of frosted lamps. So far as the authors know, however, no systematic study of the effects of frosting incandescent lamps has ever been undertaken. Such an investigation was therefore outlined at the Bureau of Standards several years ago, and although many observations have been made the subject is by no means exhausted.

These results of frosting may be classified under three general heads: (1) Change in Absorption; (2) Change in Distribution; (3) Change in Life.

In conjunction with the study of the change in distribution many observations were made on the mean spherical reduction factors of a number of types of filaments. In fact, owing to the importance of this question in its bearing on the commercial rating of incandescent lamps on a basis of mean spherical candlepower, much attention was given to this part of the investigation. The results will, therefore, be discussed in a separate section of the paper.

[1] Presented in abbreviated form under the title of "The Effect of Frosting Incandescent Lamps" before the National Electric Light Association, Washington, D. C., June 6, 1907.

[2] Cravath and Lansingh, Electrical World, March 17, 1906, p. 567. See also Electrical World, May 26, p. 1082, and June 23, p. 1304; 1906.

1. APPARATUS AND METHODS.

The principal apparatus employed in the investigation were a Reichsanstalt precision photometer bench on which the measurements of mean horizontal intensity and the determinations of distribution curves were made, and a Matthews integrating photometer on which mean spherical candlepowers were obtained. The former instrument has been described fully in a previous paper.[3] The determination of mean horizontal candlepower was made in every case by rotating the lamp about its axis at a speed of 200–250 r. p. m. In the case of lamps having a pronounced flicker at that speed a single auxiliary mirror, shown diagrammatically at *M*, Fig. 1, was used. As has already been pointed out by the writers in a paper[4] on the determination of the mean horizontal intensity of incandescent lamps by the rotating-lamp method, by combining on the photometer screen light emitted in two mutually perpendicular directions in the horizontal plane, the flicker due to the nonuniform-

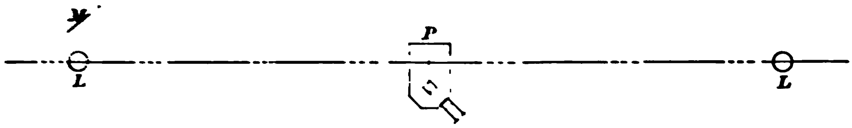


Fig. 1.—*Sketch Showing Stationary Auxiliary Mirror in Position.*

ity of the horizontal distribution curve of the lamp is greatly reduced, and accurate measurements can be made. Without some device of this kind it is impossible to obtain accurate results for certain types of lamps with the rotating-lamp method. In determining the mean vertical distribution curves of the lamps the speed of rotation was generally about 200–250 r. p. m. For lamps with pronounced flickers higher speeds were used, as it is impracticable to use the auxiliary mirror in these measurements.

The universal rotator which was employed in determining the vertical distribution curves is shown in Fig. 2. This instrument has recently been designed and constructed in the instrument shop of the Bureau. The authors desire to acknowledge their indebtedness to Mr. A. H. Schaaf and Mr. Oscar Lange for valuable aid in designing the instrument, and to Mr. R. Hellbach for painstaking

[3] This Bulletin, 2, p. 1; 1906.

[4] This Bulletin, 2, p. 415; 1906.

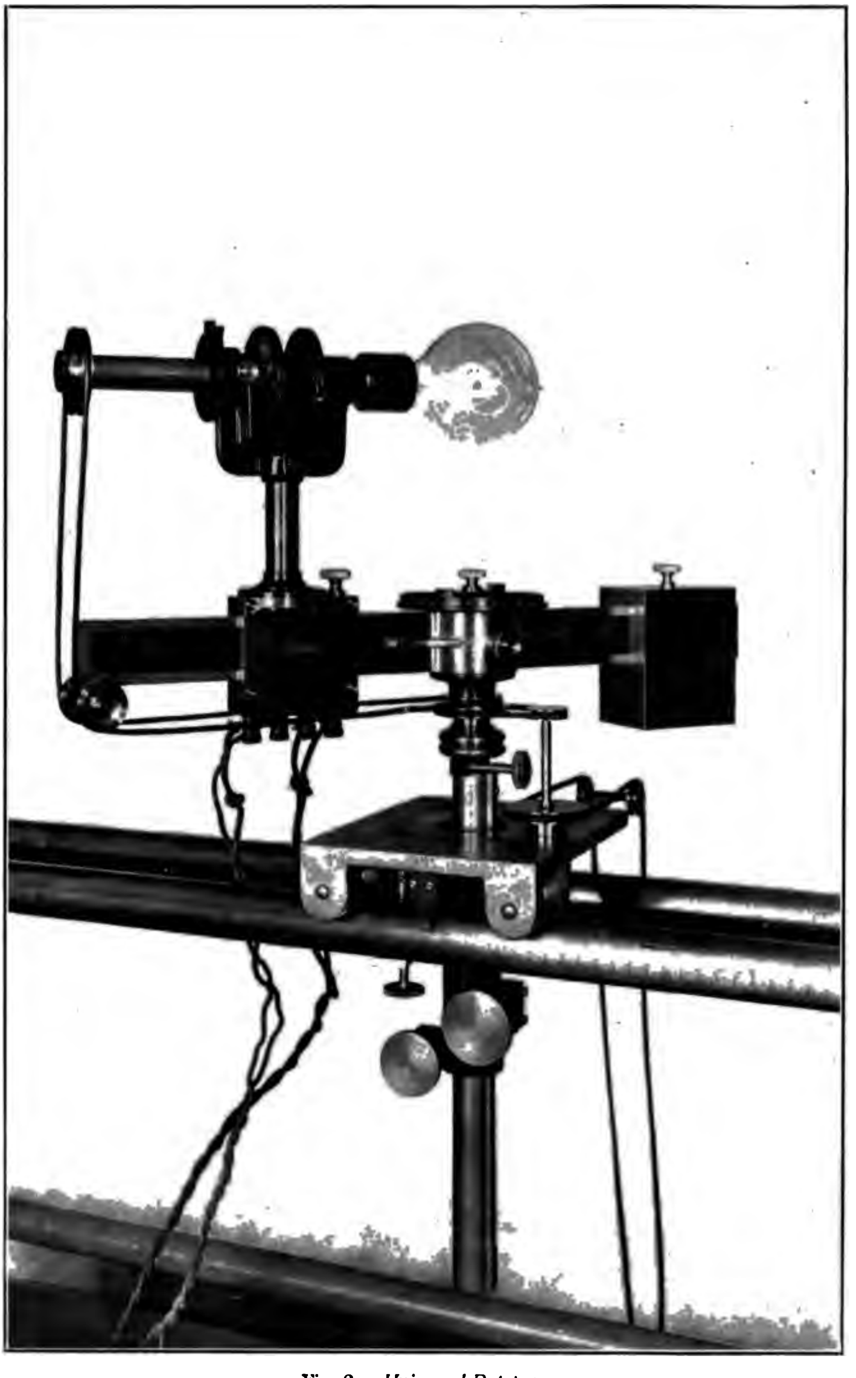


Fig. 2. —*Universal Rotator.*

care in constructing it. Inasmuch as there is not to be had, either in the United States or abroad, an entirely satisfactory universal rotator for laboratory purposes, it may not be amiss to describe here briefly the instrument made at the Bureau and used with entire satisfaction.[5]

This instrument is so designed that it can be mounted directly on any standard photometer bench. As shown in Fig. 2, it is mounted on a standard carriage supplied with the Schmidt and Haensch photometer. By the use of a counterpoise it is in equilibrium in all positions, and hence produces no strain on its support. The axis of rotation is horizontal at all times, permitting the use of mercury cups. If these are well made and well amalgamated the shaft can be driven at a speed of 500 or 600 revolutions per minute without throwing an appreciable quantity of mercury. Incandescent lamps of all sizes from 4 cp to 100 cp can be centered and measured, and even many of the ordinary shades and reflectors can be mounted with the lamps.

Since there is no strain on any part of the instrument, a divided circle and index with clamp screw can be used instead of a notched wheel. This permits of angular settings with an accuracy of 10 or 15 minutes for any desired angle, whether an even degree or a fraction of a degree. In most rotators on the market only angular settings at 5° intervals can be obtained, whereas it is frequently desirable to study distribution curves at much closer intervals in the neighborhood of rapidly changing curvatures.

Finally, the instrument is provided with a second graduated circle at right angles to the other, so that the instrument can be used as a universal lamp support, as well as a universal rotator. Any angle of latitude or azimuth can be obtained, so that not only the vertical distribution, but also the distribution in any latitude, can be determined.

The Matthews integrating photometer which was used throughout the investigation is shown in Fig. 3. In general principle it is similar to that originally described by Professor Matthews,[6] but in detailed design it has been modified somewhat, both in theory and

[5] The Bureau will be glad to furnish drawings of this instrument to anyone desiring them.

[6] Proc. A. I. E. E., 20, p. 1465; 1902.

in mechanical construction. Instead of arranging the mirrors at equal angular intervals, beginning with one in the horizontal, use was made of the results of a previous theoretical investigation[7] by one of the present authors. It was shown in that investigation by considering several simple cases of distribution curves, that the arrangement of mirrors completely satisfying Case III ($I_\theta = \cos\,\theta$), would best satisfy all practical cases. The mirrors were therefore placed at the respective angles deduced in the previous paper. According to this arrangement there is no mirror in the horizontal, but the mirrors are situated symmetrically in the two hemispheres, so that mean hemispherical as well as mean spherical intensities can be determined.

The instrument shown in Fig. 3 was built in the instrument shop of the Bureau. It is 10½ feet high and contains twenty pairs of mirrors. The lamp rotator, which is equipped with four mercury contacts, two for current, and two for potential leads, has two sockets, one upright and one inverted, so that lamps with soft filaments that will not support their own weight can be mounted, and even rotated at a low speed. The comparison lamp is mounted on a carriage which is moved back and forth by means of a pulley-wheel and steel tape. The latter, graduated in millimeters, passes under an index, from which the distance of the comparison lamp can be read.

In using the instrument the substitution method is employed, i. e., a lamp, or number of standard lamps, whose mean spherical candlepowers are known, are first placed in the rotator and measured, and then the test lamps are substituted and measurements are made on them. A measurement consists in determining the distance at which a lamp known as the comparison lamp must be placed in order to secure a photometric balance. From the inverse ratios of the squares of the distances of the comparison lamp, corresponding to a photometric balance on the test and standard lamps, the mean spherical candlepower values of the test lamps in terms of the mean spherical candlepower values of the standard lamps can be computed.

The adjustment of the mirrors is such that accurate ratios of mean spherical candlepower can be obtained even between lamps

[7] This Bulletin, **1**, p. 255; 1905.

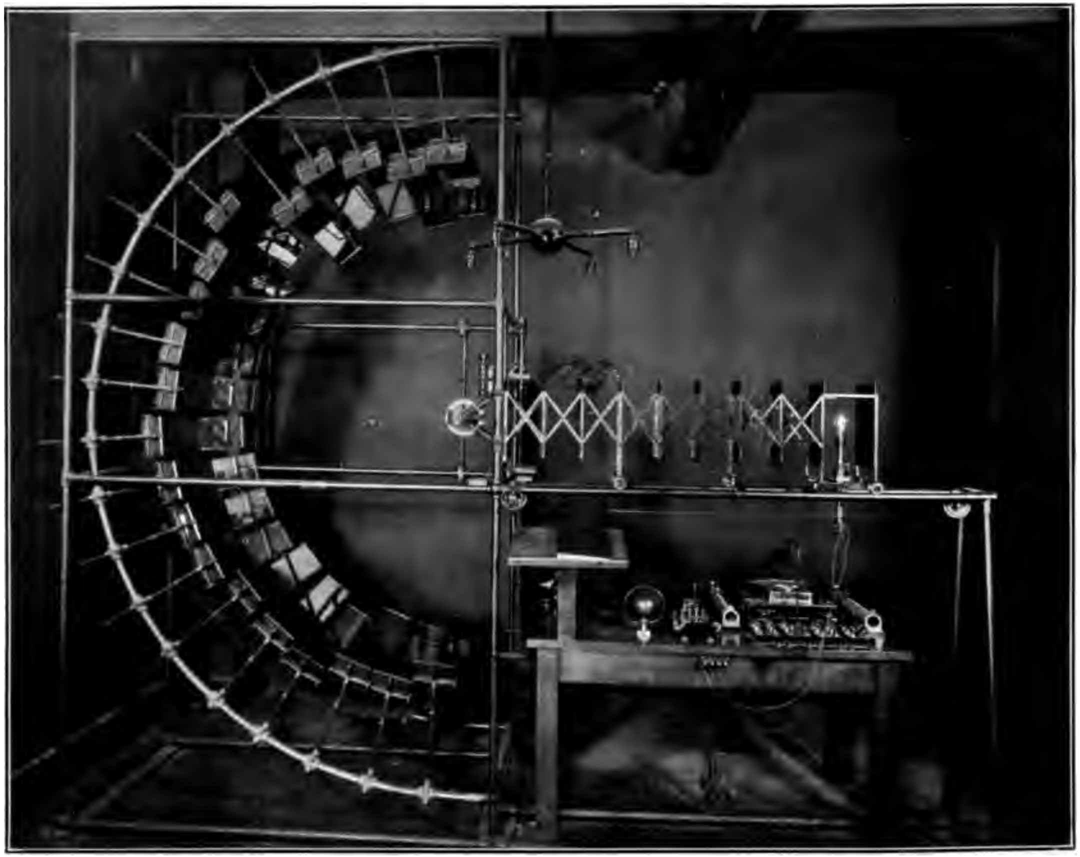


Fig. 3.—*Matthews Integrating Photometer.*

with such widely different polar-distribution curves as the double filament lamp and the downward-light lamp. However, in order to

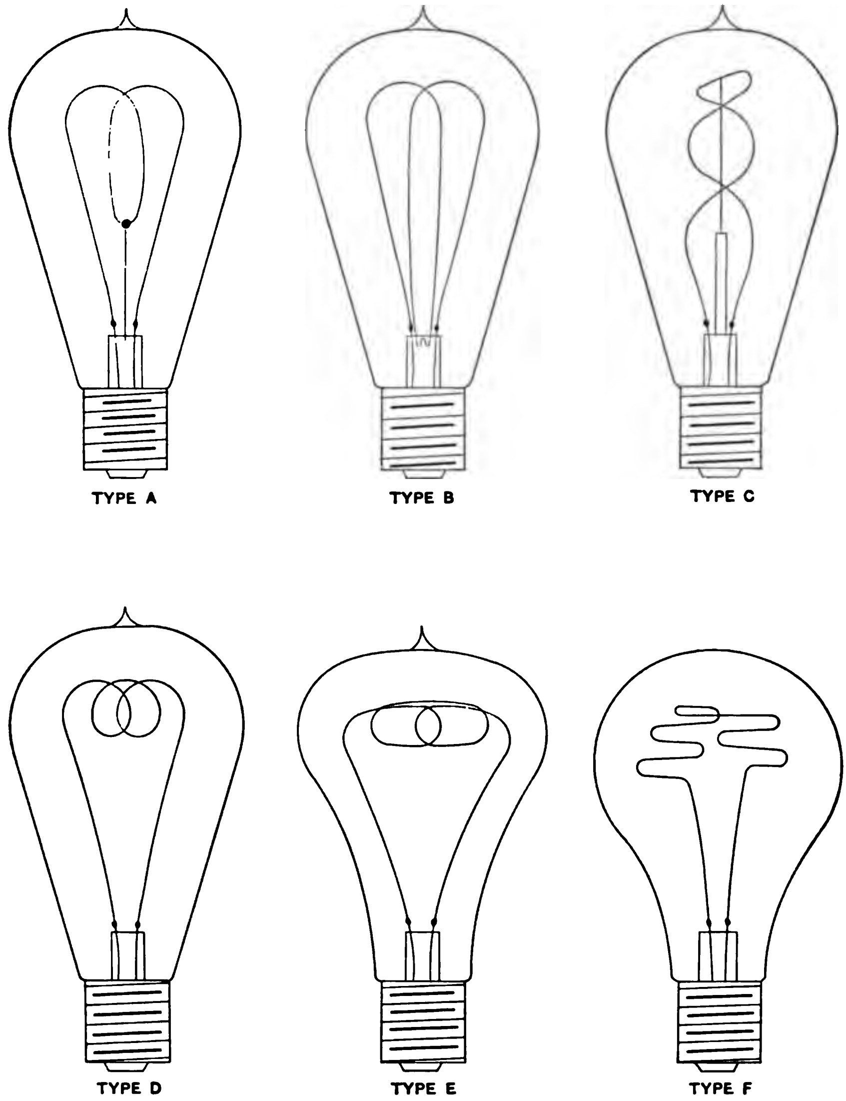


Fig. 4.—*Types of Filaments Investigated.*

avoid any possible error that might result if the instrument were to get out of adjustment, the substitution method is carried further.

In determining the mean spherical candlepower of lamps of any type of filament, lamps of a similar type of filament are used as standards.

2. CHANGE IN ABSORPTION.

In studying the change in absorption due to frosting, six different types of lamps were used. These are shown in Fig. 4. The six types are as follows: Oval anchored (type A in the figure), double filament (type B), spiral filament (type C), double round coil (type D), double-flattened coil (type E), and downward-light filament (type F). Twenty-five 16-candlepower, 110-volt lamps of each type were obtained directly from the factories, and all were seasoned so that changes in candlepower would not occur during the investigation. Several lamps of each type were carefully calibrated for mean horizontal and mean spherical candlepower for use as standards for that type, and all subsequent measurements on lamps of any type were made in terms of the standards of the type.

Each lot of lamps were measured for mean horizontal and mean spherical intensity, and then sent to the factory to be frosted. After being returned from the factory the lamps were again measured for mean horizontal and mean spherical candlepower. The decrease in mean spherical intensity is taken as the change in absorption due to frosting. The decrease in intensity is spoken of as a *change* in absorption rather than as the absorption itself, because there is always some absorption in the glass even when there is no carbon deposit on the inside and no frosting on the outside of the bulb. The frosting can scarcely be said to absorb light by extinction, it merely diffuses it, and in this diffusion some luminous energy which otherwise would pass through the outer surface of the bulb is compelled to traverse the glass, and whatever deposit there may be on the inside of the glass, a third and fifth time, and thus suffer further absorption. It is probably not the frosted surface that absorbs the energy, however, but the glass, and the carbon deposit on the inside of the bulb.

TABLE I.

Change in Absorption Due to Frosting.

Oval anchored		Double filament	Spiral filament	Double round coil	Double flat-ened coil	Downward light
Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7
(acid)	(acid)	(acid)	(acid)	(acid)	(acid)	(acid)
3%	3%	5.5%	1.5%	3%	4%	6%
4	3	5.5	2	3.5	4.5	6.5
4	3	6	3	4	4.5	6 5
4.5	3.5	6	3.5	4.5	5	6.5
4.5	3.5	6.5	4	4.5	5.5	6.5
4.5	4	6.5	4	4.5	5.5	7.5
4.5	4	6.5	4	4.5	5.5	7.5
5	4.5	7.5	4.5	4.5	5.5	7.5
5	4.5	6.2%	4.5	5	5.5	8
5	5	(sand)	4.5	5	6	8
5.5	3.8%	5.5%	5	5.5	6	8
5.5	(sand)	6.5	5	5.5	6	8
6	5%	6.5	5.5	6	6.5	8
6	5.5	6.5	5.5	6.5	6.5	8.5
6	5.5	7	5.5	7	7	8.5
6.5	5.5	7.5	6.5	4.9%	7.5	9
6.5	5.5	8	6.5		8	7.5%
7	5.5	8.5	6.5		9	
8	6	7.0%	7		9	
5.3%	6		4.7%		6.2%	
	6					
	6					
	5.6%					

In Table I are given the observed values of change in absorption due to frosting for the individual lamps of seven lots, obtained from different lamp factories and representing six different types of filaments, two of the lots having filaments of the oval-anchored type. As stated previously, the figures given represent the percentage decrease in mean spherical intensity due to frosting. The changes in mean horizontal intensity will be discussed later in connection with the changes in the distribution of the light due to frosting.

In the first two columns are given the values for the two lots of oval-anchored filament lamps. Half of the lamps of Lot 2 were frosted by the acid process and half by the sand-blasting process. It is interesting to note the uniformity among the values of the

lamps of each kind, and the difference between the average absorption coefficients for the acid-frosted and the sand-blasted lamps. The average value for the former is 3.8 per cent, with a range from 3 to 5 per cent for the individual lamps. For the latter the average is 5.6 per cent, with a range from 5 to 6 per cent. On the other hand, the average value for the lamps of Lot 1, all of which were frosted by the acid process, is 5.3 per cent, which is nearer to the value for the sand-blasted lamps of Lot 2 than to that for the lamps frosted by the acid process.

The only other lot of lamps of which parts were frosted by each of the two methods is Lot 3. Here again the acid-frosted lamps show a smaller absorption than the sand-blasted lamps, but the difference is not as great as that obtained with the lamps of Lot 2. This is easily accounted for by the fact that the surfaces of the sand-blasted lamps of Lot 3 were of a much finer grain than those of Lot 2. It was difficult to separate the sand-blasted lamps of Lot 3 from those frosted by the acid process.

The total range in the average absorption coefficients for the acid-frosted and sand-blasted lamps of the seven different lots is from 3.8 per cent for the acid-frosted lamps of Lot 2 (oval-anchored lamps) to 7.5 per cent for the acid-frosted lamps of Lot 7 (downward-light lamps). The mean value for the seven different lots is 5.7 per cent.

The question arises whether the figures given in Table I are to be taken as indicative of the degree of uniformity to be expected in the frosting of lamps at different factories, and of the frosting of individual lamps at any one factory. Another pertinent question which might be raised is whether the average absorption coefficient of 5.7 per cent which was found for lamps that had been *seasoned* applies equally well to new lamps. Since, in order to discuss fully the results on absorption in their bearing upon these questions it would be necessary to anticipate what will be said in regard to the change in life due to frosting, any further discussion of Table I will be deferred until the effect of frosting on life has been presented.

Before passing to the next part of the paper, however, it is well to call attention to the probable errors of observation in making the measurements from which Table I was computed. An error of 1 per cent in determining the mean spherical candlepower of an indi-

vidual lamp either before or after frosting would make a difference of 1 per cent in the observed absorption coefficient, i. e., a lamp showing an apparent change in absorption of 4 per cent might in reality have undergone a change of 3 per cent or 5 per cent. If in each of the two determinations—before and after frosting—an error of 1 per cent had been made, it is possible that the observed change in absorption might be in error by 2 per cent, although this would be quite improbable.

With the great number of observations to be made and the consequent speed with which they were conducted, it was impossible to give to each measurement the care requisite to obtain an accuracy better than 1 per cent. There is every reason to believe, however, that the observed average change in absorption is well within 1 per cent of the true value for those lamps.

Attention is called to this question of probable error, in order that in considering this and subsequent tables too much weight may not be given to small differences in individual lamps.

3. CHANGE IN DISTRIBUTION.

A second important effect of frosting incandescent lamps is the change produced in the polar distribution curves of the lamps. It would seem at first thought, perhaps, that frosting the bulb of an incandescent lamp would produce a more uniform distribution of the light; in other words, the spherical reduction factor, i. e., the ratio of the mean spherical to the mean horizontal candlepower, would approach unity. Such, however, is not the case. The shape of the lamp bulb is an important determining factor. If we supposed the frosted bulb to act as a perfect mat surface, i. e., to transmit no light directly but to scatter or diffuse the light completely, and if we assumed the form of the filament such that the whole frosted surface of the bulb were uniformly bright, then we could predict with reasonable certainty the approximate distribution of the light around the lamp. If the shape of the bulb were spherical, the intensity would be the same in all directions, and the reduction factor would be unity. If the bulb were a long, slender cylinder, the intensity would be a maximum in a direction normal to the axis of the cylinder, but would decrease as we approached the ends of the cylinder, the reduction factor being approximately 0.79.

In the actual case of frosted incandescent lamps the problem is not nearly so simple. The frosting is never so complete as to eliminate all direct transmission, and the shape of the bulb is not a simple geometrical figure, particularly if the effect of the base is considered. But the shape of the bulb has a marked influence on the distribution curve, as will be seen shortly from the experimental results.

There are two ways of showing the effect of frosting on the distribution—(1) by comparing the spherical reduction factors before and after frosting, and (2) by actually plotting the distribution curves of plain and frosted lamps. The second method is more satisfactory, but requires many more observations. We have used both methods. The average reduction factors for a number of lamps of each of the six different types of filaments described previously were determined before and after frosting. The values obtained for the individual lamps of the various types will be given below (section 4).

TABLE II.

Average Reduction Factors and Absorption Coefficients for Regular Lamps.

Lots	Types of filament	Reduction factors		Absorption coefficients	
		Plain	Frosted	Mean spherical	Mean horizontal
No. 1 (acid)	Oval anchored	0.826	0.825	5.3%	5.0%
No. 2 (acid)	Oval anchored	.824	.825	3.8	4.0
No. 2 (sand)	Oval anchored	.828	.825	5.6	5.4
No. 3 (acid)	Double filament	.806	.784	6.2	3.7
No. 3 (sand)	Double filament	.809	.797	7.0	5.9
No. 4 (acid)	Spiral filament	.914	.863	4.7	−0.9
No. 5 (acid)	Double round coil	.884	.885	4.9	5.0
No. 6 (acid)	Double flattened coil	.972	.984	6.2	7.3
No. 7 (acid)	Downward light	1.064	1.027	7.5	4.2

In Table II the average reduction factors before and after frosting are given in the third and fourth columns. The reduction factor of the oval-anchored lamps is substantially the same before and after frosting, showing no tendency to approach unity. The change in the reduction factor for all the other types of lamps is small except

for the spiral-filament and downward-light lamps. The former shows a decrease in reduction factor of 5.5 per cent and the latter a decrease of 3.5 per cent—that is, the effect of frosting is to diminish the mean spherical candlepower relatively more than the mean horizontal. This is also shown by a comparison of the spherical and horizontal absorption coefficients. In the fifth column the average spherical absorption coefficients are copied from Table I. In the sixth column the changes in horizontal absorption are given. The large decrease in reduction factor for the spiral-filament lamps is shown here as an actual increase in mean horizontal candlepower due to frosting, whereas the decrease in mean spherical intensity on frosting is over 4.5 per cent. It is evident, therefore, that the changes in mean horizontal intensity are no criterion of the actual absorption due to frosting.

A comparison of the spherical reduction factors before and after frosting, however, does not give a fair idea of the relative distribution curves under the two conditions. Thus, although the ratio of mean spherical to mean horizontal intensity is not altered apprecia bly by frosting the oval-anchored filament lamps, the distribution of light in the two cases is not the same. Before discussing the relative distribution curves (Figs. 5 to 13) of the plain and frosted bulb lamps of each of the six types of filament studied, some experiments made with lamps having special bulbs will be described.

In order to show experimentally that the shape of the bulb is an important factor in determining the distribution of the light around frosted lamps, we obtained, through the courtesy of the General Electric Company, a number of regular oval-anchored filaments mounted in 3⅛-inch spherical bulbs, of which some were frosted. Subsequently we also obtained, through the kindness of the National Electric Lamp Association, a number of double-flattened coil and downward-light filaments mounted in the straight sides bulb SS–19, such as is commonly used with the oval-anchored filament, but which is not supplied with the regular double-flattened coil or downward-light lamp.

These various special lamps were treated in the same way as the regular lamps, i. e., their spherical reduction factors and distribution curves were obtained. The average spherical reduction factors for each special type, both plain and frosted, are given in Table III.

TABLE III.

Average Reduction Factors for Special Lamps.

Types of filament	Shapes of bulb	Reduction factors	
		Plain	Frosted
Oval anchored	3½ in. round bulb	0.840	0.887
Downward light	Straight sides SS-19 bulb	.982	.938
Double-flattened coil	Straight sides SS-19 bulb	.995	.935

In the study of the special lamps, four plain and seven frosted oval-anchored lamps were used, four plain and four frosted double-flattened coil lamps, and five plain and two frosted downward-light lamps. Owing to the small number of lamps studied, the precise numerical values obtained are not to be insisted upon, but the general conclusions drawn from the results would seem to be perfectly definite.

The effect of the shape of the frosted bulb is evident at once in the difference between the reduction factors for the regular frosted and the special round-bulb frosted lamps with oval-anchored filaments. The value for the former is 0.825, that for the latter 0.887, a difference of over 7 per cent. Another striking illustration is afforded by the downward-light lamps. The average reduction factor for the regular frosted-bulb lamps is 1.027, whereas the reduction factors for two downward-light filaments mounted in SS–19 frosted bulbs were found to be 0.935 and 0.94. The average value 0.938 is almost 9 per cent different from the average value for the regular lamps. The differences in the shapes of the distribution curves will be discussed presently.

Another interesting result, which also becomes clearer when we consider the distribution curves, is the change in the reduction factor of plain-bulb lamps with change in shape of bulb. Only a few lamps were studied and the numerical differences found are not very large, but we are quite certain that the shape of the bulb has an appreciable influence on the reduction factor and on the distribution curve. Thus the average reduction factor for the four special round-bulb lamps is 0.840, whereas only one lamp of the forty-five regular-bulb lamps studied has a value that high, the average for

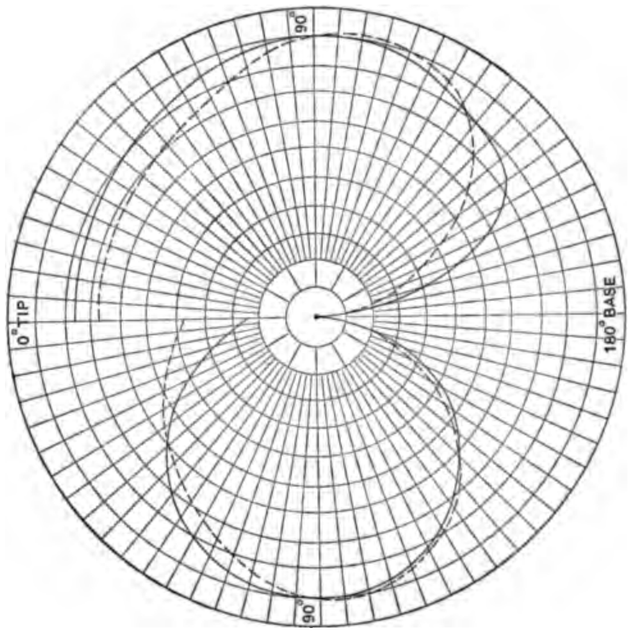
the forty-five lamps being 0.826. The effect is more noticeable with the downward-light lamps. The average reduction factor for the regular lamps is 1.064; for the five special lamps it is 0.997, a difference of almost 7 per cent. Moreover, the lowest value for any of the twenty-three regular lamps is higher than the highest value for any of the five special lamps.

The differences both for the plain and the frosted lamps are clearer when we plot the distribution curves. In Figs. 5 and 6 are shown the average vertical distribution curves for the plain and the frosted double-filament and spiral-filament lamps—the two extreme types which are supplied with the ordinary straight sides bulb SS–19. In plotting all the curves the mean horizontal intensity is taken as unity. No attempt was made to determine the exact form of the curve in the neighborhood of the base, since it depends to such an extent upon the style of rotator used, the distance at which the measurements are made, etc. The measurement nearest the base was made at 165°, or 15° from the base. The intensity at the base was assumed to be zero. As stated previously, in determining the distribution curves the speed of rotation was 200–250 r. p. m. for all lamps except those having pronounced flickers at that speed. For these lamps higher speeds were used, so that the curves obtained may be slightly different from those that would be obtained at low speeds if it were possible to make accurate readings with a badly flickering illumination of the photometer screen.

The two curves to the right in Fig. 5 are for the spiral-filament lamp, the solid curve applying to the plain-bulb lamp and the dotted curve to the frosted-bulb lamp. Similarly, the two curves to the left in Fig. 5 are for the plain and frosted bulb double-filament lamp. In Fig. 6 these same curves are reproduced in a different arrangement in order to compare the two plain-bulb curves and the two frosted-bulb curves.

It is evident, first, from Fig. 5 that frosting modifies greatly the distribution curve of the plain lamps. In particular, it is interesting to note that in the double-filament lamp the tip candlepower is increased relative to the mean horizontal intensity, whereas in the spiral-filament lamp it is decreased. From Fig. 6 it is seen that the curves of the two frosted lamps are more nearly alike than the curves of the two plain lamps, due to the fact that both types of

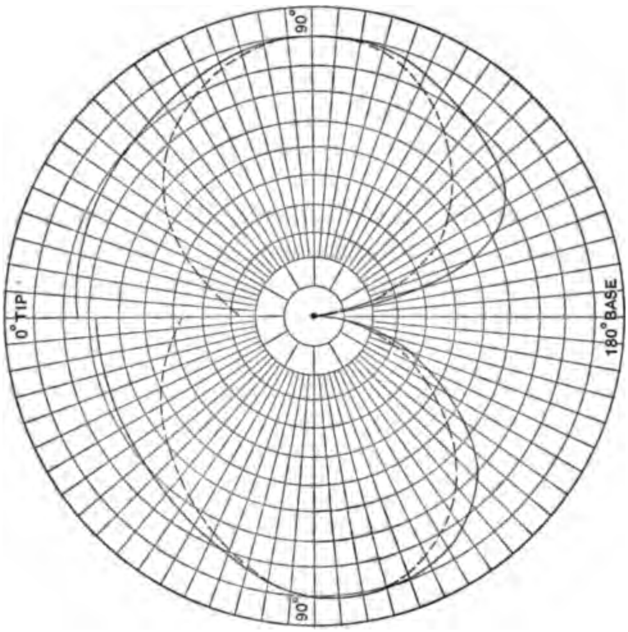
DOUBLE AND SPIRAL FILAMENTS
REGULAR BULBS.



DOUBLE FILAMENT
PLAIN ————
FROSTED - - - - - -

SPIRAL FILAMENT
PLAIN ————
FROSTED - - - - - -

Fig. 5.



FROSTED
SPIRAL FILAMENT ————
DOUBLE " - - - - - -

PLAIN
SPIRAL FILAMENT ————
DOUBLE " - - - - - -

Fig. 6.

filaments are in the same bulb, and the shape of the bulb impresses its character on the distribution curves of the frosted lamps.

In Figs. 7 and 8 are shown similar curves for oval-anchored filaments in regular SS–19 and special round bulbs, plain and frosted. In Fig. 7 the two curves to the right are for the plain and frosted regular bulbs; the two to the left are for the plain and frosted special round bulbs. The effect of the shape of the frosted bulb is clearly evident from the two curves to the left in Fig. 8, of which the solid curve applies to the regular bulb and the dotted curve to the special round bulb, in both of which regular oval-anchored filaments were mounted. The two curves to the right in Fig. 8 show the effect of the shape of the plain bulb on the distribution curve.

This effect is more pronounced in the case of downward-light filaments mounted in their regular and in straight sides SS–19 bulbs, as shown by Figs. 9 and 10. These curves are analogous to those for the oval-anchored filament in Figs. 7 and 8. The effect of the shape of the bulb, both for the frosted and plain lamps, is quite noticeable.

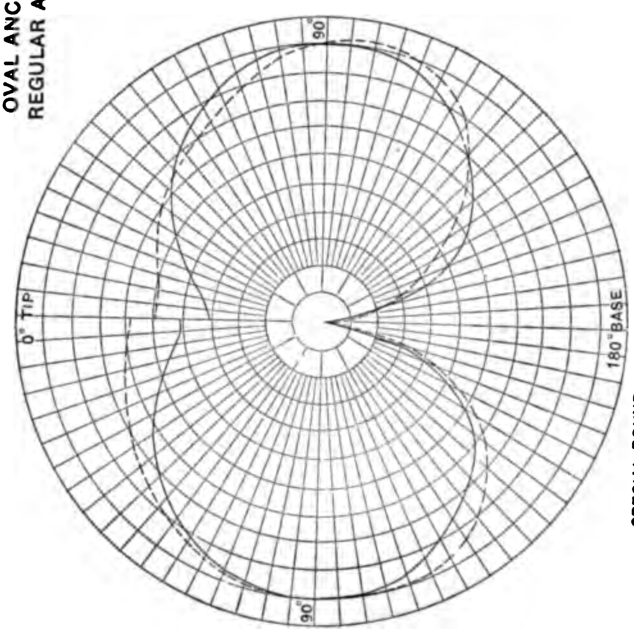
In Figs. 11 and 12 similar curves for double-flattened filaments mounted in their regular and in straight sides SS–19 bulbs are given. The same general effects are noticed with this type of filament as with the oval-anchored and downward-light filaments. In Fig. 13 the distribution curves for the double round-coil filament in regular plain and frosted bulbs are shown.

The curves given in Figs. 5–13 are the *average* vertical distribution curves of the lamps, obtained by rotating each lamp about its axis of figure and determining the mean latitudinal intensity for different latitudes. A complete study of the effect of frosting would involve a determination of the distribution of light in each latitude. It would seem to us that too little significance is usually attached to the distribution of the light in space. In order properly to design fixtures for illuminating a room it is as necessary to know the distribution of the light in any latitude as it is to know the average distribution in the vertical plane.

4. SPHERICAL REDUCTION FACTORS.

It is generally recognized that the proper basis of comparison for lamps having different distribution curves is the ratio of the total flux of light emitted to the rate at which energy is supplied to the

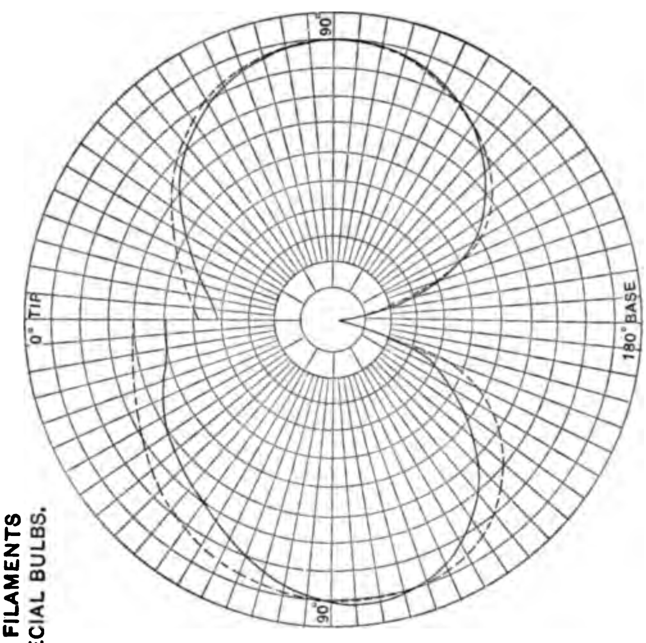
OVAL ANCHORED FILAMENTS
REGULAR AND SPECIAL BULBS.



SPECIAL ROUND BULB
PLAIN ————
FROSTED - - - - -

REGULAR BULB
PLAIN ————
FROSTED - - - - -

Fig. 7.



FROSTED
REGULAR BULB ————
SPECIAL ROUND BULB - - - - -

PLAIN
REGULAR BULB ————
SPECIAL ROUND BULB - - - - -

Fig. 8.

DOWNWARD LIGHT FILAMENTS
REGULAR AND SPECIAL BULBS.

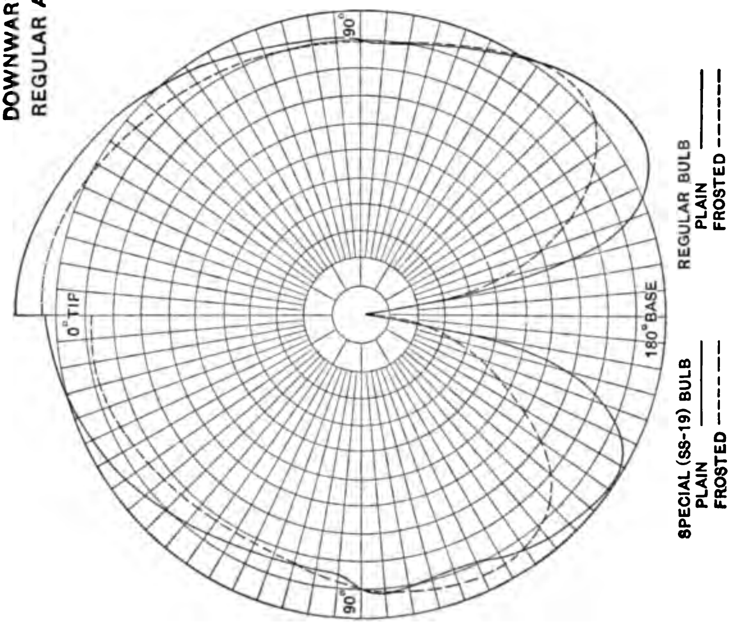


Fig. 9.

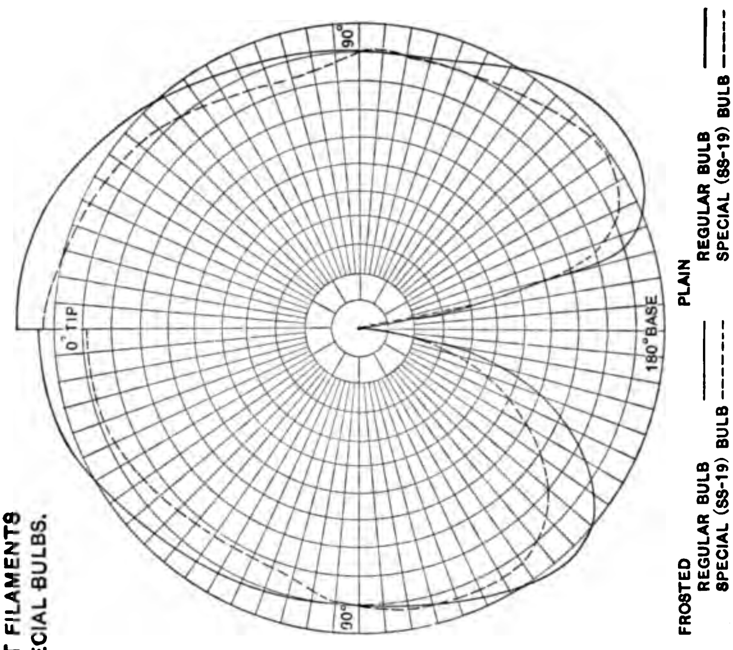


Fig. 10.

DOUBLE FLATTENED COIL FILAMENTS
REGULAR AND SPECIAL BULBS.

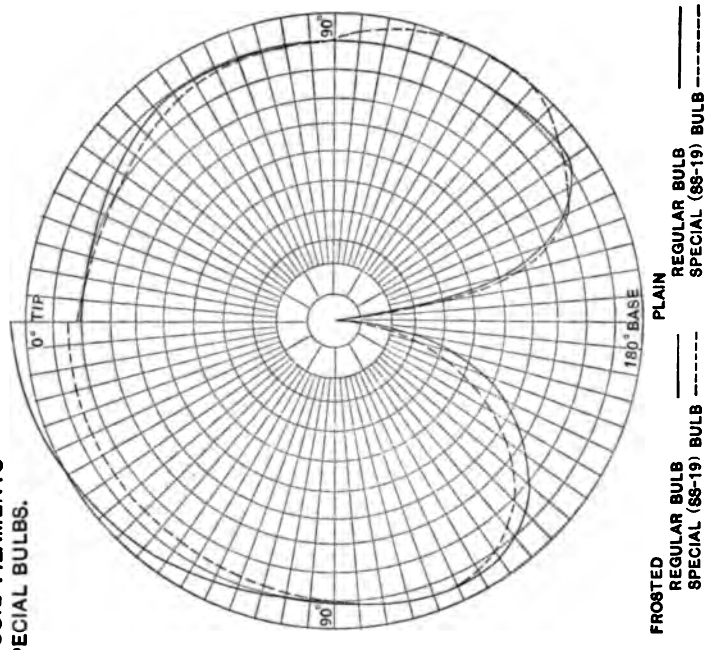


Fig. 12.

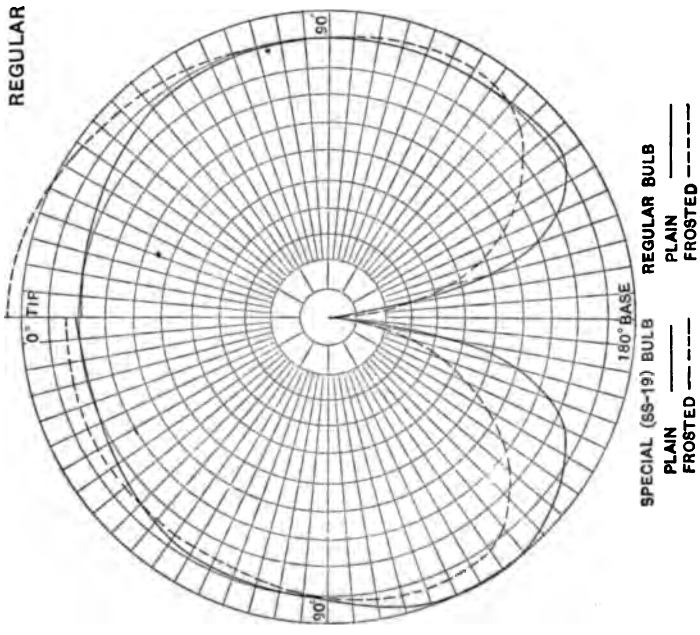


Fig. 11.

lamp. This involves a determination of the total flux of light, or, more commonly, of the mean spherical candlepower of the lamp. Although various types of integrating photometers for determining the mean spherical candlepower of incandescent lamps have been devised—some of them very excellent for laboratory purposes—there has never been developed such a photometer which could be in-

DOUBLE ROUND COIL FILAMENTS
REGULAR BULBS

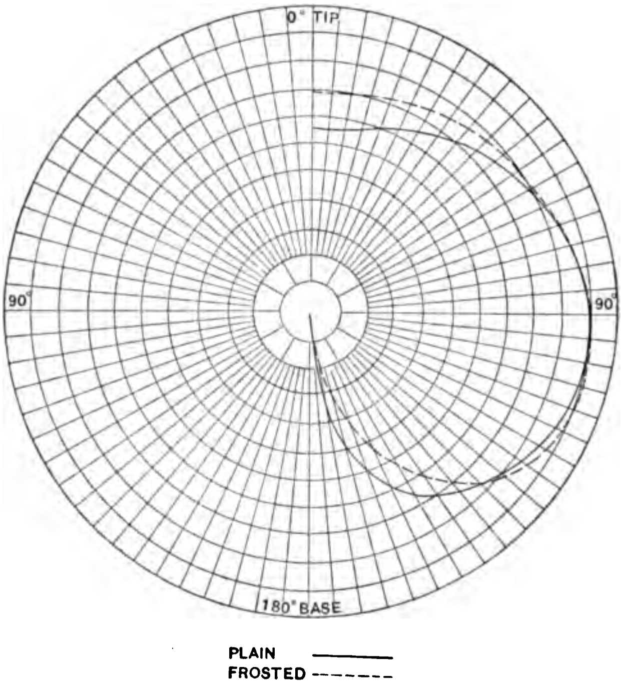


Fig. 13.

stalled and used with satisfaction in a lamp factory. As a result, very few lamps have been purchased heretofore in the United States on this basis. Until an integrating photometer suitable for use in lamp factories and testing stations is placed on the market the mean spherical rating can best be accomplished by the use of spherical reduction factors. This method has been incorporated in the lamp

specifications recently adopted for use by most of the departments of the Government.

The idea of the spherical reduction factor is an old one, and it has long been known that for any type of incandescent lamp the spherical reduction factor is approximately constant for individual lamps of that type. Many investigations of the values of spherical reduction factors for different types of incandescent lamps have been published, but owing to the recent renewed interest in the question, and the improved facilities at our disposal for measuring mean spherical candlepower, it seemed desirable to include in this investigation on the effect of frosting an auxiliary study of the spherical reduction factors of the six types of lamps used.

TABLE IV.

Spherical Reduction Factors of Regular Plain Bulb Lamps.

Oval anchored		Double filament	Spiral filament	Double round coil	Double flattened coil	Downward light
Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7
0.82	0.81	0.80	0.89	0.87	0.97	1.04
.82	.81	.80	.90	.87	.97	1.04
.82	.82	.80	.90	.87	.97	1.04
.82	.82	.80	.90	.88	.97	1.04
.82	.82	.80	.90	.88	.97	1.04
.82	.82	.80	.90	.88	.97	1.05
.82	.82	.80	.90	.88	.97	1.05
.82	.82	.80	.91	.88	.97	1.06
.82	.83	.80	.91	.88	.97	1.06
82	.83	.81	.91	.88	.97	1.06
.82	.83	.81	.91	.88	.97	1.06
.83	.83	.81	.91	.88	.97	1.07
.83	.83	.81	.91	.88	.97	1.07
.83	.83	.81	.91	.89	.97	1.07
.83	.83	.81	.91	.89	.97	1.07
.83	.83	.81	.91	.89	.97	1.07
.83	.83	.81	.92	.89	.97	1.07
.83	.83	.81	.92	.90	.97	1.08
.83	.83	.81	.92	.90	.97	1.08
.83	.83	.81	.92	.90	.98	1.08
.83	.83	.81	.92		.98	1.08
.83	.83		.93		.98	1.09
	.84		.93		.98	1.09
			.93		.98	
			.93			
0.825	0.827	0.806	0.912	0.884	0.972	1.063

In Table IV are given the results obtained on the individual lamps of each type before they are frosted.[8]

It is seen that for forty-five lamps of the oval-anchored type obtained from two different manufacturers the total range is from 0.81 to 0.84, the greatest observed deviation from the mean being less than 2 per cent. The agreement among the observed values for lamps of the double-filament type (Lot 3) and for those of the double flattened-coil type (Lot 6) is even better. The largest differences were observed with lamps of the downward-light type (Lot 7), where a maximum deviation from the mean of about 2.5 per cent was found. One would expect the variations among lamps of this type of filament to be larger than those among lamps of other types, because of the relatively rapid change in intensity in the neighborhood of the horizontal for downward-light filaments.

But when we contrast the 2 or 2.5 per cent maximum deviations of individual lamps of any one type from the mean value for the type with the 20 or 30 per cent differences between the various mean values for the different types, it is apparent that in the absence of a cheap, convenient, and accurate photometer for measuring mean spherical candlepower directly, the spherical-reduction factor offers an excellent substitute in the commercial rating of lamps on the basis of mean spherical efficiency.

5. CHANGE IN LIFE.

It has long been recognized that the useful life of a frosted incandescent lamp taken to 80 per cent of its initial mean horizontal candlepower is only a little more than one-half of the life of a corresponding plain-bulb lamp. The only explanation which had been advanced, so far as the authors know, previous to that suggested by the present investigation is that the temperature of the frosted lamp is higher, due to the increased absorption by the bulb, and that therefore the lamp reaches any given point in its life—e. g., the 80 per cent point—in a shorter time than that required for the corresponding plain-bulb lamp.

[8] The slight decrepancies between values given in Table II and those given in Table IV are due to the omission of the figures in the third decimal place in the values of the individual lamps in Table IV. These were taken into account in computing the means given in Table II.

Without entering at present into a discussion of the possible temperature effects, it is sufficient to notice that if the shortened useful life can be attributed to this cause, it is very probable that, due to the same cause, the total life of a frosted lamp up to the time when the filament burns out would also be very much less than that for the plain lamp. On the contrary, tests carried out at the laboratories of the National Electric Lamp Company by Mr. S. E. Doane indicated that the average total life of frosted lamps is not very different from that of corresponding plain lamps. It would seem, therefore, that some explanation other than that of the effect of temperature must be sought. A possible explanation of the phenomenon occurred to one of the authors in the course of the present investigation. An experiment devised to test it showed conclusively that it would account for at least a large part of the effect, if not for all of it. This explanation, together with a brief account of the preliminary experiments supporting it, was published in the Electrical Review[9] several months ago.

The explanation, as outlined in that paper, from which we quote, is as follows: "If we consider the case of a new plain-bulb lamp, a certain small percentage of the total flux of light emitted by the incandescent filament is absorbed by the glass envelope surrounding the filament. When the lamp is frosted a large part of the light which in the plain bulb would pass through the outer surface of the bulb is diffusely reflected back through the glass. In this way a relatively large part of the total flux of light passes through the glass more than once, and so the frosted bulbs show an absorption about 5 per cent greater than that for the plain bulbs.

Now, the actual absorption coefficient of glass is quite small, so that it is readily seen that if in any way the absorption coefficient is increased appreciably, the apparent absorption due to frosting would be increased greatly. This is what happens when with increasing life the strongly absorbing film is deposited on the inside of the bulb. The effect is the same as if the absorption coefficient of the glass had been increased greatly." In the case of an old plain lamp all the light passes through the carbon film once, a small percentage passes through three times, a still smaller percentage five times, and

[9] Electrical Review, April 6, 1907; p. 556. See also this Bulletin, 3, p. 341; 1907.

so on. When the lamp is frosted the percentage of light that passes through more than once is very much larger, so that the carbon film has an opportunity to absorb a much larger percentage of the total flux. According to this theory, although at any time the filament in the frosted bulb may be emitting the same total flux of light as that emitted by the filament in the plain bulb, the absorption of light in the carbon film is much greater in the one case than in the other, and so the apparent intensity of the frosted lamp at any time during life is less than that of the plain lamp, the difference in intensity increasing with the number of hours the lamps have burned.

In order to make a quantitative determination of this effect, after convincing ourselves by a few qualitative experiments that the effect was a real one, ten comparatively new lamps and twelve old lamps that had dropped to 80 per cent in candlepower were carefully measured for mean horizontal and mean spherical intensity. They were then sent to a lamp factory and frosted by the acid process, care being exercised to see that the frosting was as nearly uniform for the different lamps as it was possible to obtain. The lamps were then returned to the Bureau of Standards and measured. The new lamps were found to have decreased in mean horizontal intensity by about 4 per cent on the average, the individual lamps agreeing among themselves to within less than 2 per cent. On the other hand, the older lamps decreased in mean horizontal intensity by 18 per cent, or 14 per cent more than the new lamps. In other words, the apparent absorption of the frosting was approximately four and one-half times as great for the old lamps as for the new lamps. This means that if we were to assume no difference in the physical or mechanical properties of plain and frosted lamps, a lot of plain lamps which would decrease 20 per cent in candlepower in a definite number of hours would in the same number of hours decrease approximately 32 per cent if they were first frosted. The useful life of the frosted lamps to 80 per cent of initial candlepower would be about 60 or 70 per cent of the useful life of the plain lamps, a value in approximate agreement with that commonly accepted. This shows that whatever effects may be produced in the lamps by frosting them, the mere absorption by the deposited carbon film, as explained above, is sufficient to account for a decrease in useful life of about 30 or 40 per cent.

The new lamps decreased about the same in mean spherical as in mean horizontal candlepower, whereas the old lamps decreased several per cent more in mean spherical intensity. This is probably due to the uneven distribution of carbon on the inside of the bulb.

Several weeks after the above explanation was printed in the Electrical Review, Mr. Preston S. Millar published in the Electrical World[10] an account of some experiments made upon frosted lamps at the Electrical Testing Laboratories. It is very interesting to note that the results of Mr. Millar's experiments are in very good agreement with those obtained at the Bureau of Standards and further substantiate the theory outlined above. Quite recently Dr. A. E. Kennelly has put this theory into a mathematical form in a paper published in the Electrical World.[11]

In the preliminary paper printed in the Electrical Review an experiment was outlined to determine whether there are any other elements entering to bring about the short useful life of frosted lamps. This experiment has just been completed. Out of a number of 110-volt, 16-cp, 3.1-wpc oval-anchored filament lamps five lots of twenty-two lamps each were selected and designated as Lots A, B, C, D, and E. The nearest even voltage for each lamp was found corresponding to an initial specific consumption of 3.3 watts per mean horizontal candle. In all the subsequent photometric measurements the lamps were burned at these voltages. On the life rack, however, in order to hasten the completion of the investigation, the lamps were maintained at a voltage 12 volts higher than that at which they were measured on the photometer. This voltage corresponded to an initial specific consumption of approximately 2.3 watts per mean horizontal candle.

The five lots of lamps were measured carefully for initial mean horizontal candlepower, and then all the lamps except those of Lot A were placed on the life rack. The lamps of Lot B were burned for 9 hours, those of Lot C for 37 hours, and those of Lots D and E for 78 hours, at which time it was expected that the lamps would have reached the 80 per cent point. On measuring all the lamps for mean horizontal candlepower it was found, however, that the D

[10] Electrical World, April 20, 1907; p. 798.

[11] Electrical World, May 18, 1907; p. 987.

and E lamps had only decreased in candlepower to 83 per cent of the initial value.

All the lamps with the exception of those of Lot E were then sent to the factory to be frosted. Upon their return they were all measured again for mean horizontal candlepower and placed upon the life rack, with the exception of those of Lot D, which already had burned for 78 hours and had decreased in candlepower (before being frosted) to 83 per cent of their average initial value. The lamps of each of the three Lots A, B and C were burned the requisite number of hours to make the total time of burning 78 hours.

In this way all the lamps were made to burn 78 hours, but the paths followed by the various lots were different. Thus, Lot A burned the total 78 hours after having been frosted; Lot B burned 9 hours while plain and 69 hours after having been frosted; Lot C burned 37 hours plain and 41 hours frosted, and Lot D burned the entire 78 hours before being frosted. The average candlepowers of each lot at the various stages are given in Table V. In the first

TABLE V.

A Comparative Study of the Changes in Candlepower of Plain and Frosted Lamps During Life.

	Mean horizontal candlepower					Mean spherical candlepower	
	A	B	C	D	E	A	D
Average initial candlepower	15.31	15.29	15.15	15.26	15.29	12.61	12.62
0 hrs Plain	100%	100%	100%	100%	100%	100%	100%
0 hrs Frosted	98					98	
9 hrs Plain		99					
9 hrs Frosted		95					
37 hrs Plain			94				
37 hrs Frosted	86	85	87				
78 hrs Plain				83	83		82
78 hrs Frosted	72	72	73	73		70	70
Horizontal absorption coefficient	2% (0 hrs)	4% (9 hrs)	7% (37 hrs)	12% (78 hrs)			

column are given the different times at which photometric measurements were made, together with a statement of the condition of the lamps at that time, whether plain or frosted. In the next five

columns are given the average mean horizontal candlepowers of the five different lots at the various stages of their life. In the first line the actual average candlepower of each lot is given, but in the succeeding lines the candlepowers are expressed in per cents of the initial value of each lot. The average candlepower of each lot determined immediately after the lamps were returned from being frosted is underscored, so that it is easy to see how many hours each lot burned before and after having been frosted.

It is interesting to note the marked agreement among the different lots upon reaching the same point in the curve by different paths. Thus, after 37 hours Lot A had decreased to 86 per cent, Lot B to 85 per cent, and Lot C (frosted) to 87 per cent, although the A lamps were frosted initially, the B lamps after 9 hours, and the the C lamps after the entire 37 hours burning. Again, at the end of 78 hours the four lots A, B, C, and D had decreased in candlepower to the same value within about 1 per cent, although the A lamps burned the entire 78 hours after frosting, whereas the D lamps were frosted at the end of the 78 hours, the other two lots having been frosted at intermediate points. In other words, these tests would seem to indicate that the frosting has no appreciable effect upon the life curve of the filament, the short, useful life of frosted lamps being due entirely to the increased absorption of the light by the deposited carbon film, as explained above.

Mr. Millar, in the paper referred to previously, described one set of experiments in which the candlepower of some frosted lamps which had burned a number of hours and which were soiled, increased by about 10 per cent upon being washed. One can readily see how the candlepower of frosted lamps could be changed considerably by the presence of dirt on the surface. In order to see whether this element played any part in the investigation at the Bureau, three of the A lamps which had burned 155 hours were measured for mean spherical candlepower before and after being washed. The increase in candlepower after the lamps were cleaned was about 1 per cent on the average. Since these three lamps had been exposed double the time used in the test, the effect of dust on the bulbs was evidently entirely negligible.

Upon completing the candlepower measurements after 78 hours, all of the frosted lamps, and, in addition, the lamps of Lot E, which

had burned to 78 hours, but which had not been frosted, were placed on the life rack and kept burning, in order to see whether there is any indication of an effect of frosting on the total life of the lamps. The average total life of the lamps of each group until they burned out is as follows: Lot A, 104 hours; Lot B, 118 hours; Lot C, 133 hours; Lot D, 123 hours; Lot E, 118 hours. If frosting played an important part in determining the actual life of the filaments, the average total life of each successive group, in the order of the letters of the alphabet, would be greater than the preceding. There is no indication, however, of such a sequence. It is true that the life of the A lamps is the shortest, but the life of the E lamps, which should be the longest, is no greater than that of the B or D lamps, and is much less than that of the C lamps, which burned nearly three-fourths of their life after having been frosted. It is evident, therefore, that this test shows no marked effect of frosting on the life of the filament.

As shown in the last two columns of the table, the two extreme lots A and D were measured also for mean spherical candlepower. Here, as in the mean horizontal measurements, the average candlepower of the frosted lamps after 78 hours burning is the same, independent of whether the lamps are frosted first and burned subsequently, or vice versa. The decrease in mean spherical candlepower, however, is slightly greater than the change in mean horizontal intensity. This agrees with the results given in Table V.

In discussing the change in absorption due to frosting, the question was raised as to whether the absorption of new lamps is the same as that of seasoned lamps. The answer to this is evident from a consideration of Table V. The change in horizontal candlepower due to frosting is given in the last line of the table. The A lamps, which were frosted when new, showed an absorption of 2 per cent; the B lamps, frosted after 9 hours, an absorption of 4 per cent; the C lamps, after 37 hours, an absorption of 7 per cent; and the D lamps, after 78 hours, an absorption of 12 per cent. The average value of 5.7 per cent given earlier in the paper for seasoned lamps is therefore probably several per cent higher than the correct value for new lamps.

Since, in seasoning the lamps which were used in studying the change in absorption due to frosting, no special care was exercised